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ANCHORING U.S. COMPETITIVENESS: REVISITING THE ECONOMIC RATIONALE FOR TECHNOLOGY POLICY

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Richard H. White

September 1995

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INSTITUTE FOR DEFENSE ANALYSES
IDA Central Research Program

PREFACE

This paper was written as part of the IDA Central Research Program. Based on the authors' collective experience with Clinton administration technology investment strategies and programs, it provides a retrospective assessment of the administration's technology policy goals and accomplishments.

Dr. Jay Stowsky, currently the Director for Research Policy and Development, University of California, spent 2 years as a Senior Economist on the President's Council of Economic Advisors from 1993 to 1995. While on the Council, Dr. Stowsky presided over the Administration's technology investment portfolio. Prior to his work on the Council, Dr. Stowsky was an Associate Professor of Economics at Berkeley and worked extensively with the Berkeley Round Table on the International Economy (BRIE).

Dr. Richard White is a Project Manager at IDA who specializes in the areas of technology policy, technology management, and the economic impact of technological change. Dr. White has been involved with the Technology Reinvestment Project for the past 3 years, and has participated in the development of the Department of Defense Critical Technology Plans and Technology Strategies. Prior to his employment at IDA, Dr. White served 2 years as an economic development advisor in Micronesia, and 8 years as a maritime economist at the Department of Transportation.

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Investments in applied technologies are an important part of the Clinton administration's efforts to foster long-term economic growth and national security. Many federal government technology programs relate directly to the goals and priorities of U.S. industry, reflecting a transition in federal science and technology (S&T) policy driven by the end of the Cold War and the intensification of global economic competition.

During the previous half-century, U.S. S&T investments supported basic science and procured the first technological fruits of space- and military-related research as products for NASA and the Department of Defense.[1] Through the mid-1970s, commercial spillovers from federally funded R&D and procurement helped the United States to maintain a clear leadership position on all fronts—political, scientific, military, and economic. The United States used its position to promote open trade and global economic development to the benefit of both its allies and itself. In the process, it enabled the emergence of sophisticated economic competitors, the most successful of whom, many believe, used government policy more purposefully than did the U.S. to leverage science and technology for national economic performance.

The end of the Cold War has profoundly altered the political landscape and shifted the rationale for many government technology investments. Foreign competition has increased and advanced technologies are are rapidly developing domestically and abroad. In response to these changes, the Clinton administration is emphasizing cost-shared government-industry investments in high-risk technologies for commercial application, and dual-use technologies for application by both military and commercial industry. Government-industry partnerships play a key role in strengthening the competitiveness of American industry in domestic and international markets. This policy is showcased by such efforts as the Advanced Technology Program, the Technology Reinvestment Project, Manufacturing Extension Partnerships, Manufacturing Education initiatives, and Cooperative Research and Development Agreements.[2]

In this paper we apply our collective knowledge of the administration's ongoing efforts to draw conclusions about the appropriate role of government in stimulating economic benefits through technology "investments." Given that the congressional

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1 This approach to S&T investments is associated most notably with the policy prescriptions of Vannevar Bush. See V. Bush (1945), *Science: The Endless Frontier* Washington D.C.: U.S. Government Printing Office.

2 See the Clinton Administration technology policy as stated in, *Technology for America's Economic Growth* and *Technology for Economic Growth: Checklist of Clinton Administration Key Accomplishments.*

Republican majority elected in November 1994 has slated most of the administration's programs for termination or substantial downsizing, it is appropriate at this time to reexamine the economic rationales put forth by supporters of these efforts.

We begin with the economic and social welfare implications of technological change and the economic evidence supporting the claim that such change is central to economic growth and increased productivity. In our view, unexploited opportunities exist wherein government can intervene to correct market failures attendant to the process of technological development. We next examine the notion that the economic returns to an innovation are often only partially captured by the innovator, because some amount of learning and know-how from the process of technological development inevitably "spills over," free of charge, from the innovator to his or her competitors, customers and suppliers. We note the evidence that such spillovers are, at first, geographically concentrated, and we discuss the implications of this fact for national policies designed to foster competitive industries in high technology sectors. We conclude with a set of recommendations for designing future federal technology investments that provide the greatest leverage for purposes of regionally based economic growth, while also supporting government agency missions and meeting broader social policy goals.

TECHNOLOGICAL INNOVATION, SOCIAL WELFARE, AND ECONOMIC GROWTH

Today it almost goes without saying that rapid technological change is central to the way we live and work. Though the average person remains unaware of the detailed and chaotic processes involved in technological discovery, development, and production, we all are profoundly and directly affected by the rapid pace of innovation. But despite the pervasive influence of technological advances, until the past decade U.S. government policy makers generally maintained a "hands-off" approach vis-à-vis technology as a means to improve social welfare through economic growth. This is particularly interesting given that approximately one-half of all research and development in the U.S. spending is funded by government dollars.

We know that, indirectly, government policy has always influenced the environment in which technological change takes place. For instance, within the last two centuries the course of the industrial revolution in the U.S. was shaped by policies embodied in laws pertaining to slavery and the length of the working day, regulations concerning working conditions, product liability statutes, and public education programs.

Such policies greatly influenced private incentives for engaging in research, and shaped decisions about the production and consumption of different types of goods and services. However, only within the past several decades have proposals to use technology as an instrument of economic policy come into fashion—so-called technology policy.

Simple mathematics tells us that small variations in economic growth rates will result in dramatically different outcomes: at an annual growth rate of 2.1 percent, per capita income doubles every 34 years; at a 5.8 percent rate, every 12 years. These increases are cumulative, so if the rate of growth for the next century is 2.1 percent per year, per capita income will be 8 times greater than it is today 100 years from now. As a result, we cannot ignore even small influences on the growth rate of the economy since they can cumulate to very large changes—for better or for worse—in a nation's standard of living.

Economic theory and empirical evidence support the central role of technology in sparking and sustaining long-term economic growth. Technological change fuels economic growth by enhancing the productive efficiency of industry. Inputs may be rearranged to reduce the overall costs of production, or new and better production recipes may enable quantity and quality of outputs to rise even as the costs of inputs remain constant or decline. Such technological advances may result from costly, purposive research aimed at inventing and appliying new technologies, or they may arise unexpectedly as a by-product of experience as in "learning-by-doing" (production) or "learning-by-using" (consumption).

Technological change does not come without its price, however, and has often brought with it considerable social angst in the form of labor displacement and unemployment.[3] Such fears spurred the now infamous Luddites, who went so far as to smash machinery in the mid 1800s. Similar concerns permeate organized labor agreements in the U.S. today as a result of reorganization of the workplace, employment of new technologies, and reengineering.[4]

Economists like to point out that when a new process technology increases productivity, making it possible to achieve the same or a greater amount of output with

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3 Technological change may also lead to environmental degradation and health problems, which for the sake of brevity we choose not to treat here.

4 Paul Krugman, "Europe Jobless, America Penniless?" *Foreign Policy*, 1994, pp. 14–34, and "Technology's Revenge," *Wilson Quarterly*, Autumn 1994, pp. 56–64.

fewer workers, the lower prices, higher wages, and/or higher profits that result will still eventually translate into new jobs. This, they say, is due to inevitable increases in demand for less-expensive products wrought through greater production efficiencies. Increased employment also results from the fact that consumers now have more money left over after purchasing less-expensive goods to buy more of the same or other goods. Over time, even within the industry experiencing job-displacing productivity growth, such effects lead to new employment opportunities in quantities at least as great as those created through dislocation.[5]

Economists also argue that even when employment in an industry does shrink absolutely over time due to productivity-enhancing technological change, in the long run prices decline, wages increase, and profits rise. Because such changes induce growth elsewhere in the economy, in the long run productivity growth due to technological change will not increase overall unemployment.

In the shorter run, however, technological change may in fact negatively affect large numbers of workers. History shows that the Industrial Revolution caused average wages in the United Kingdom to more than double—from approximately 81 cents to approximately $2 per hour in 1990 dollars—between the 1820s and the 1870s, and during the following half century unemployment in Britain showed no appreciable rise. But history also records that the Industrial Revolution in Great Britain was associated at first with a decline in the real wages of most workers, and that the wider benefits of technological progress did not become evident until about 1840, a half-century after large-scale factory production began. Whatever economic circumstances they ultimately enjoyed or endured, in the short run (a run of as much as 50 years) the Luddites were right: they did lose their jobs.[6]

Thus, the basic task of public officials in representative democracies has been difficult, but clear. Traditionally, the task has been to design policies that make beneficial economic and technological change socially and politically sustainable. Policies to nurture and sustain the process of technological discovery have been combined with strategies to ease the pain (or, less generously, to localize and contain the pain) of individual and community-wide adjustment, an adjustment that is nevertheless

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5 Of course temporarily unemployed workers are thrown into an emotional and financial upheaval. Costs accrue in the form of increased social pathologies—alcoholism and drug abuse, depression and divorce—not to mention the destruction of local communities due to the need to relocate.

6 Krugman, op. cit., pp. 56–54.

required if those very same individuals and communities are ever to capture the greater ultimate gains from faster long-term growth.

EMPIRICAL EVIDENCE LINKING ECONOMIC GROWTH AND TECHNOLOGICAL CHANGE

As noted earlier, considerable empirical evidence supports the claim that technological change is central to economic performance through its profound influence on productivity. Studies also reveal that technology has a tendency to produce uncompensated benefits, or "spillovers," for consumers and rival companies. As a result, companies will invest only up to the point where they can capture the lion's share of the economic returns. Significant opportunities for further innovation and growth may remain unexploited unless government does something to stimulate additional investment.

Economic Research

Economists have studied the role of technology, research, and development in economic growth for almost 40 years. In the 1950s, seminal macroeconomic work by Solow[7] and Abramowitz[8] established the extant limitations of economic knowledge regarding the bases for productivity growth. These writings posit that the existing macroeconomic models failed to explain the origins of productivity improvements and, ultimately, economic growth based on factor inputs—labor and capital—because they ignored a residual factor they termed "technology." Subsequent investigations reinforce the conclusion that broad-based statistical models reveal little information about the "residual" origins of productivity and growth, thereby implicitly confirming the important role of technology and other "non-physical" factors in determining economic performance.[9]

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7 R. M. Solow (1957). "Technical Change and the Aggregate Production Function," *Review of Economics and Statistics*, 39, pp. 312–320.

8 M. Abramovitz (1956). "Resource and Output Trends in the United States Since 1870," *American Economic Review*, 46, pp. 5–23.

9 In 1956, a study by Abromowitz concluded that over the period 1869 to 1953 the primary determinant of growth in U.S. per capita output was improved productivity rather than increases in capital stock. Robert Solow, in the following year, examined the U.S. economy for the time frame 1909–1949, a period in which gross output per household doubled. He concluded that only 21 percent of this growth could be attributed to the increased use of capital inputs, and that 28 percent was attributable to labor and other factors; traditional factor inputs could not account for the remaining 51 percent of growth. Such results led to a variety of subsequent studies on the role of innovation and technological change

Macroeconomists generally agree then, that technological change is central to economic performance. But while macroeconomic studies suggest the economic importance of technological change, they do not answer the question, To what degree is there an unexploited gap between private investments and potential social returns? This question is important because in the presence of significant spillovers private returns may deviate significantly from social returns. That is, in cases where individual firms cannot capture all the gains from their research and development investments, spillover benefits lead to social returns that exceed private returns. Another way of stating this is that where spillovers are large, private returns significantly understate the actual benefits to society (that is, all companies and consumers) captured in the social return. In particular, firm-level analysis and case studies suggest that technology investments yield not only sizable private rates of return, but also potentially large returns to society at large.[10]

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at the macroeconomic level, including important work by Kendrick, Denison, Kuznets, Jorgensen, Griliches, Gollop, and Fraumeni. This work is conveniently summarized in Boskin and Lau's international study completed in 1992 which arrived at similar conclusions regarding the importance of technological change to economies worldwide. Attempting to overcome many restrictive assumptions of earlier studies, they examined economic growth in the five largest industrial nations and found that, consistent with the earlier works, technological progress is by far the most important source of growth for modern, industrialized countries. Michael J. Boskin and Lawrence Lau (1992), "Capital, Technology, and Economic Growth," in *Technology and the Wealth of Nations*, pp. 17–55.

10 Also see more recent work by Mansfield: E. Mansfield, J. Rappoport, A. Romeo, S. Wagner, and G. Beardsley (1977). "Social and Private Rates of Return from Industrial Innovations," *Quarterly Journal of Economics*, pp. 221–240; E. Mansfield (1991). "Academic Research and Industrial Innovation," *Research Policy* 20, pp. 1–12). A. B. Jaffe (1989) also points out the importance of academic research in creating appropriable and social returns. "Real Effects of Academic Research," *The American Economic Review* 79, pp. 957–970).

Authors such as Griliches, and Evanson, Waggoner and Rutan, have pointed out that significant returns may also be attributed to technological change across a collection of firms. In what has become considered a classic study, Griliches measured the social returns on investments in hybrid corn: Z. Griliches (1958). "Research Costs and Social Returns: Hybrid Corn and Related Innovations," *Journal of Political Economy* 66, pp. 419-431. Z. Griliches (1964). "Research Expenditures, Education, and the Aggregate Agricultural Production Function," *The American Economic Review* 54, pp. 961-74. Using a straightforward approach that looked at total benefits and total costs over a 45-year period, the study estimates a social return of 700 percent per year. Looking at agricultural research in general, Evenson, Waggoner, and Ruttan estimated that the returns from researched funded at the state level, including an estimate of spillovers to other states, yielded a yearly rate of return of 95 percent, while science-oriented research earned 110 percent (R. E. Evenson, P. E. Waggoner, and V. W. Ruttan (1979). "Economic Benefits from Research: An Example from Agriculture," *Science* 205, pp. 1101–1107). Furthermore, 55 percent of these gains occurred within the states that provided the funding, while the remaining 45 percent were spillovers to other states.

A more sophisticated approach to estimating spillovers from technological advances in a specific good is offered by T. F. Bresnahan and M. Trajtenberg (1995). General Purpose Technologies, 'Engines of Growth?' *Journal of Econometrics* 65, pp. 83-108) calculated the area under a derived demand curve to measure changes in consumer welfare. In this study the question was how much worse off would consumers have been if the price/performance ratio for mainframe computers had not declined from its

Recently, empirical work has also begun to document the complex relationship between productivity and research and development. For instance, Jaffe[11] has inferred the existence of spillovers by looking at the effects of one firm's R&D on the productivity of another's. This study found indirect evidence of research and development spillovers: (1) firms performing R&D in heavily researched areas have more patents per dollar of spending and higher returns in terms of accounting profits, and (2) firms with low R&D spending have lower profits and market share if competitors are R&D intensive.

Finally, Paul Romer has recently advanced the notion that the rate of economic growth is a function of the stock of human capital in the form of technology represented by the collective knowledge of business, academia, and government.[12] Essentially, ideas themselves lead to the technological change that brings about growth. If too few resources are dedicated to research and development (and increasing the stock of new ideas), the rate of economic growth will be lower than it otherwise could have been.

Government Technology Policies

While economists have been able to establish the important role of technological change in fostering economic growth, there is significant disagreement regarding public policy prescriptions to take advantage of this knowledge. It is not simply an issue of practice, but ideology as well. That is, government technology investment policies cannot be determined directly from economic findings about technological change because the past is not prologue—technological change is not readily predictable in advance. This dilemma—how to deal with such uncertainty—is central to the debate about the appropriate role of the public sector in the economy. Different schools of economic thought, representing different ideological positions within the profession, offer conflicting policy prescriptions.[13]

1958 level. Here, gains for companies using computers were estimated at $68 million, while gains to consumers were estimated to be at least $225 million.

11 A. B. Jaffe (1986). "Technological Opportunity and Spillovers of R&D: Evidence From Firms' Patents, Profits, and Market Value," *American Economic Review* 76, 984–1001.

12 Paul M. Roemer (May 1987). "Growth Based on Increasing Returns Due to Specialization," AEA Papers and Proceedings, pp. 56–62. Paul M. Roemer (1983). *Dynamic Competitive Equilibria With Externalities, Increasing Returns and Unbounded Growth.*

13 This is not the same as differences in party affiliation; many liberal Democratic economists take a hard line against intervention in this area.

Proponents of "free market" principles for government conclude that, when faced with uncertainty, government should remain "hands-off" at the firm and sector level and promote private sector technology investments through policies aimed at the overall performance of the economy. In their view the marketplace is the most efficient vehicle for promoting economic growth and overall social welfare, and tampering with the marketplace is only warranted in rare instances when it can be demonstrated that markets are unable to function properly without outside assistance—so-called market failure.[14]

Other economists, who we term "interventionists," argue that government action can sometimes improve the way the market works, particularly at the sector or firm level. In particular, science and technology represent important areas where market failure is often present. Firms may forgo S&T investments for numerous reasons, including fear that competitors will easily share in findings (appropriability), management demands for quick and demonstrable results (imperfect intervention), difficulties in spreading risk among firms within an industry (collective action or coordination problems), and the existence of large up-front costs for R&D or facilities (complicated anti-trust laws). Together these problems lead to significant underinvestment in technology development by the private sector relative to potential social and private benefits that might otherwise accrue.

Therefore, despite the growing body of evidence pointing out the potentially significant returns to technology investments, until recently prevailing political attitudes prevented their use by the public sector to directly promote national economic performance. This conservative predisposition, that government should not intervene at the microeconomic level, did not rule out the use of R&D tax incentives to stimulate broad industrial investments in technology, nor did it rule out the use of targeted technology investments which could be directly linked to a government agency mission such as health, defense, transportation, education, agriculture, or space. Rather, policies concentrated government investments in basic research or in incipient applied technologies under conditions of great uncertainty.[15]

Hence, government intervention in the marketplace sometimes flowed from specific legislated goals affecting whole industries, as in the case of synthetic fuels,

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14 The six standard reasons for market failure are: (1) the imperfect flow of information; (2) transaction costs; (3) the nonexistence of markets for some goods; (4) market power; (5) externalities; and (6) public goods.

15 Consistent with the exhortations of Vannevar Bush as expressed in *Science, the Endless Frontier*.

breeder reactors, and supersonic transport programs.[16] More often, however, intervention came about for purposes related to public health; for military purposes, such as ARPA's investments in computing, microelectronics, and telecommunications; and, for education and training purposes, most notably through the extension program of the Department of Agriculture.

Not all of these government investments proved to be successful in achieving their heralded goals. The "big technology" programs begun in the 1960s and 1970s to redress market dislocations in the areas of energy availability and transportation are considered to have been failures, not in the least part because they substituted national prestige and public sector rationales for sound economic footing. Breeder reactors and synthetic fuels could not be justified based upon the extant price of petroleum, and the SST was not commercially viable given its limited capacity and high fuel consumption. At best these might be considered ill conceived "experiments" where technology-driven agendas were decoupled from market forces; their failures supported the free market case that the public sector should not attempt to influence the direction of innovation and markets.

Just as notable as these failures, however, were investments made in the name of mission agencies that proved important to the commercial world. Long-term investments by DoD, ARPA, and DoE in new technologies for defense, such as the integrated circuit, supercomputing, advanced network design, and materials, today help form the backbone of revolutions in commercial technologies. Investments through NIH made essential contributions to the development of new drugs new treatment protocols, and increasingly sophisticated medical equipment. The Department of Agriculture's outreach efforts, particularly their extension programs, have been essential to the world-class productivity and quality of U.S. farm goods. These counter examples tend to support the view of interventionists that government can play a constructive role in the marketplace.

Such historical lessons teach us that the vehicle *and* mode of government technology intervention in the marketplace are important in determining the ultimate success and impact of invested dollars. Massive, national technology-push efforts appeared to take on a life of their own, regardless of markets. Advanced R&D and

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16 For a history and assessment of the success of these projects see L. R. Cohen and R. G. Noll (1991). *The Technology Pork Barrel*, Washington, D.C.: The Brookings Institution.

market creation, such as those supported by ARPA, appeared to offer an important boost for technologies which had *both* mission and commercial applications.

Yet many analysts pointed to the apparent successes of Japan, Germany, Korea, Taiwan, and other economies in using government policies directed at securing national advantage in leading-edge *commercial* technologies as examples of the possible expanded constructive role of the public sector. In fact, it was this increased competition from abroad that fostered the renewed debate of the 1970s and 1980s regarding the appropriate role for the U.S. government in promoting the commercial competitiveness of American industries.

As a result of this debate, sentiment in industry and government began to shift toward the view that, in some cases, government action would not only be helpful, but essential. The most notable early manifestation of these changed principles arose during the Reagan and Bush administrations in the form of the VHSIC and SEMATEC programs. Intellectual credence was also mustered for this expanded government role through a series of public and private sector studies, including a long series by the National Academies which culminated in *The Government Role in Civilian Technology: Building a New Alliance*,[17] and a series of reports by the Carnegie Commission on Science, Technology, and Government which yielded *Technology and Economic Performance: Organizing the Executive Branch for a Stronger National Technology Base*.[18] These and other works contained policy recommendations for public strengthening of the U.S. technology enterprise through direct government support, as well as the possibility of creating a separate, commercially oriented advanced research agency modeled on the successful Defense Advanced Research Projects Agency (DARPA), now known as ARPA (Advanced Research Projects Agency).

Learning from earlier lessons and spurred by the growing technology policy literature from the late 1970s and 1980s, technology programs at the end of the 1980s and into the 1990s were structured by Congress and the Bush administration to attempt to ensure their relevance to market realities as well as national goals. The result was a

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17 Committee on Science, Engineering and Public Policy, Panel on the Government Role in Civilian Technology (1992). *The Government Role in Civilian Technology: Building a New Alliance*, Washington, D.C.: National Academy Press.

18 Carnegie Commission on Science, Technology, and Government (1991). *Technology and Economic Performance: Organizing the Executive Branch for a Stronger National Technology Base*, New York.

formula which called for industry-led activities that addressed either the mission needs of government agencies, or specific needs of industries on a pre-competitive basis.

The change from a Republican to a Democratic administration in 1993 provided an even freer hand to those who supported a greater role for government in assisting national economic performance and competitiveness. The Clinton administration proved willing to undertake the types of experimental programs so long urged by Democrats (and some Republicans) in Congress, including the expansion of existing efforts begun in the Bush years.

The Commerce Department's commercial applied technology program, the Advanced Technology Program (ATP), was vastly expanded, and a new applied dual-use program, the Technology Reinvestment Project (TRP), was begun under the auspices of the Department of Defense. Commerce's Manufacturing Extension Partnership Program (MEP) was expanded toward a goal of 100 nationally distributed centers, and the National Science Foundation was afforded funds to expand its efforts to bring applied engineering experience into university and college curricula.[19] Efforts already under way at the DOE national laboratories, to increase their commercial relevance through Cooperative Research and Development Agreements (CRADAs) with industry, were blessed and encouraged. While all of these programs purportedly aligned with existing agency missions, such as those of the Departments of Defense and Energy, their new spin was explicitly to stimulate U.S. economic competitiveness.

It is still too early to fully assess the contributions that these public sector efforts have made towards the goal of improved national economic performance and security. Initial evidence points to some significant achievements in the area of public-private sector partnerships and allows characterization of some of the strengths and weaknesses inherent in the different program vehicles used. It is particularly important, from the standpoint of public policy making, to address those issues that could influence future debates about the usefulness of government intervention for stimulating applied technology investments, particularly the issue of how we should go about the job of measuring their effectiveness, over time.

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[19] Note that the expansion of the Manufacturing Extension Partnerships Program and the new Manufacturing Education and Training Programs were initially funded out of the Department of Defense due to budget firewalls that were in place at that time. Since then MEP funding has been moved back to the Department of Commerce, and the NSF program is slated for termination by Congress.

TECHNOLOGY-RELATED MARKET FAILURE

As noted above, economists of every ideological stripe acknowledge to varying degrees that where the development of new technology is concerned, the solutions imposed by markets may be socially and economically sub-optimal. Therefore, it may be argued that where such failures exist government intervention in the marketplace is justified to pursue social benefits that would not otherwise be forthcoming. However, the existence of a theoretical or empirically supported rationale for intervention does not mean that the precise role of government in stimulating social returns is well understood. Many different and widely varying prescriptions for government policies have been advanced based on the different economic lenses employed. This is because technology is not like most other economic goods. Most other goods can be categorized as either rival or non-rival, and as either excludable (private) or non-excludable (public). Technology is a non-rival but only partially excludable good.[20]

A rival good is so classified because consumers are rivals for its use; that is, either you can use it or someone else can use it, but you both cannot use it at the same time. Most physical objects can be reasonably classified as rival goods. However, a recipe or set of instructions is non-rival. You and someone else can use a recipe or follow a set of instructions at the same time, and you can do so without diminishing their value to each other or to anyone else who might wish to use them now or in the future.

Economic goods may also be classified according to their excludability or appropriability, which is a matter of control. You can gain control over an object by obtaining physical possession of it; when your continued possession is protected by legal sanctions, you can consider that object your property. Similarly, you can gain control over a valuable piece of information by keeping it a secret; your property rights to the secret information can be protected by a patent or some other legal device.

Maintaining control is easier and less costly for some types of goods. Property rights to some goods—like an hour of labor time—are much harder to enforce. Some days you work harder than others. It is normally possible for your employer to observe the product of your labor, but it is normally not possible without costly and time-

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20 The following analysis draws heavily on the recent and influential work of economist Paul Romer. See, for example, "Endogenous Technological Change," *Journal of Political Economy* 98 (1990), pp. S71–S102; "The Origins of Endogenous Growth," *Journal of Economic Perspectives* 8 (1994), pp. 3–23.

consuming surveillance and litigation to check and enforce your degree of effort from one moment to the next.

Similarly, control over non-rival goods can be strong or weak, creating lesser or greater potential for spillovers. Legal control over access to a local cable system can be very strong if threatened sanctions are enforced. Access to the knowledge embodied in Henry Ford's automobile assembly line, on the other hand, could be only partially controlled, and other firms were able to learn about and copy what Ford did. Today, films on video, recordings on compact disc, and computer programs on floppy disk are all non-rival goods from which non-paying consumers can be only imperfectly excluded.

When control over a non-rival good is essentially non-existent, economists refer to it as a "public" good. Examples of public goods include the U.S. nuclear deterrent and research into the origins of the solar system. In these cases, no legal or other sanctions can exclude people from the benefits these goods provide, and nothing can prevent some people from becoming "free riders." Although the label "public" may seem to imply that such goods are necessarily provided by the government, this is not so—private charity is often a public good. But free rider problems due to the inability to control access to the benefits of public goods means that self-interested, profit-seeking individuals will not go into business to provide them, even though everyone would benefit significantly from their provision. Even politically conservative economists therefore typically support taxes to finance government provision of incontestably beneficial public goods.

Conversely, when it is possible to avoid planned, collective action to increase the degree of private control over an economic good, so-called collusion or monopoly, most economists tend to support policies that penalize such behavior. This reflects a fundamental tenet of neoclassical economics: when unfettered control over economic goods exists, unfettered exchanges among large numbers of self-interested buyers and sellers will lead to the most efficient allocation of goods (efficient in the sense that no one can be made better off through further exchange without making someone else worse off). From this laissez-faire perspective, collective action organized and enforced through government is only a last resort, and market allocation backed by a system of strong property rights is always a better way to go.

The dilemma for policy makers is that when it comes to the provision of technology—a non-rival good and the very engine of long-term growth—the efficient economic solution is less obvious. Return for a moment to the distinction between rival

and non-rival goods. Many of the things we buy and use are actually a combination of the two.

For example, economic distinction between your physical copy of a book and the intangible information contained within the book is important because of the difference in cost associated with producing each part. Most of the cost of producing the information (the non-rival good) is fixed, the fixed cost of producing the information for the first time. The publisher presumably paid the author thousands or hundreds of thousands of dollars, including residuals, to write the book, but it does not cost you anything to pass the book's contents along to someone else. In contrast, most of the cost of producing the physical book (the rival good) is constant, the constant cost of printing additional copies.

The high fixed cost of creation and essentially zero cost of replication that characterize the production of non-rival goods means that the establishment of enforceable property rights to them requires a grant of monopoly power over them. In the absence of at least temporary monopoly rights, no self-interested economic actor would choose to bear the high fixed costs of creating them because, once they exist, they are easy, cheap, perhaps even free to copy, and no one bears a very large cost for copying them. This is the economic justification for strong and enforceable patent rights, copyrights, and other forms of intellectual property protection.

But here also is a dilemma: if the non-rival good is a new technology, a new recipe for combining raw materials in a way that makes them more valuable, it is important to society and vitally relevant to the rate of economic growth that it be copied, rapidly and widely. Too strong a grant of monopoly power over the technological innovation will not only raise the price of copies to consumers, it will also slow the rate of discovery of subsequent inventions that build on the innovation, whether they spring from more research or from accidental discoveries by producers and consumers of the good.

A central task of technology policy is thus to control the rate of technology diffusion so that inventors can still capture enough of the economic returns to their inventions to make the costs of discovering them worthwhile, while at the same time ensuring that the technological innovation diffuses rapidly enough and widely enough to spur the rate of discovery among other inventors and among users and producers of the goods in which the new technology is partially embodied.

For public goods—goods that are non-rival, but whose diffusion is essentially uncontrollable—we attempt to achieve the right balance by letting the U.S. government pay for the necessary research with our tax dollars and then give away the results. This is not controversial so long as the benefits of producing the public good are obvious and uncontested—the polio vaccine, for example. For goods like music, movies, and microprocessor designs, goods that are non-rival but whose diffusion is amenable to strong or reasonably strong legal control, we grant producers temporary monopoly rights. Since the end of World War II, the United States has typically relied on the mechanism of peer review of competitive research grants to decide which particular public goods to support. For non-rival private goods, we rely on markets to select the most promising investments.

The dilemma is that there are still significant unexploited economic gains in the imprecise gap between these two extremes of excludability—the gap inhabited by the input we call technology. The inhabitants of this gap include non-rival goods such as the chemical principles employed in the manufacture of composite structures, the insights embodied in design tools for computer programming, and the art of keeping microscopic dust particles from contaminating computer chips in the clean room of a semiconductor fabrication facility. These are the sorts of technologies that policy makers refer to when they describe the objects of "generic" or "pre-competitive" research—some economists refer to them as industry-specific public goods. What they have in common is that they are non-rival (anyone can use them without diminishing their value to anyone else), but only partially excludable—even with effective patent protection they provide spillover benefits to consumers and producers beyond the consumers and producers who discover and initially apply them. The benefits do not spill over to all consumers and producers as in the case of a pure public good, but rather to a large subset of consumers and producers, generally tied to a particular industry or a linked set of industries.

The partial excludability, or limited appropriability of technology stems from the fact that technology is partially embedded in physical objects and partially embedded in people. Parts of a new technological recipe can be "disembodied" and easily disseminated, that is, written down in a blueprint or an operations manual, talked about at a scientific conference, or reported over the phone. Some of the recipe can be uncovered simply by using or reverse-engineering a product or piece of production equipment in which it is embedded, regardless of patent protection. And some part of the information that goes into the discovery of a new technological recipe is normally tacit; it arises from

first-hand experience and remains in the heads of the people who first discovered, developed, and applied it. This sort of knowledge can spill over when people change jobs—when one company hires key personnel away from another company, or when scientists and engineers leave the company where they have worked to establish a competing one.

Recall that the high fixed cost of creating a new technological recipe and the much lower cost of replicating it means that the incentive to invest in new technology requires a promise of monopoly power. The originator of the innovation bets that the monopoly will last long enough to enable him to capture a large share of the economic returns to the innovation, a share large enough to make the risk of his initial fixed investment worthwhile. It is in the interest of the innovator to hold on to his monopoly position as long as he can—and the temporary monopoly is in society's interest, too, because it spurs the rate of innovation and long-term economic growth. But the rate of innovation and growth will slow, as we noted earlier, if the monopoly is too secure, if it lasts too long. For growth to proceed, the spillover benefits of new technologies must not be bottled up.

Companies will try to bottle them up. Indeed, many companies prefer to use new technology for production internally for as long as possible before incorporating it in products for sale. Most of the economic benefits will be competed away, passed on to *users* of the innovation, soon after the technology is widely disseminated. Ever since the transistor was invented at Bell Labs, for example, companies have invested millions of dollars to discover improved technological recipes that would eventually reduce its cost. Yet most of the benefits from these discoveries have accrued to the users of the improved transistors, not the companies that developed them.

Companies face a quandary—the high fixed cost of their investment requires them to seek the widest possible market. Startup costs for a new technology are inherently high and only justifiable by long-term volume, so a common strategy is for a company to outspend its competitors at the start, outlast them during an unprofitable phase of market building and learning-by-doing, then reap the monopolistic returns from high volume sales. U.S. companies have been notoriously slow to embrace such long-term investment horizons, even when there is ample prospect that they will be able to capture a large share of the economic returns. One would not expect companies to pursue such long-term strategies, however, when it is clear to them at the outset that the benefits

from their investment will spill over very quickly to other producers and consumers, particularly their competitors, essentially for free.

The notion that long-term investments in research which are fundamental and applicable to many different products and processes also tend to be easily appropriated by competitors—are not excludable—has led to the distinction between competitive and pre-competitive research activities. The concept here is that when the results from research are not excludable or rival and are generic to a broad range of products and processes, from a society-wide standpoint it is more efficient if firms collaborate in their research activities and share results. Circumstances under which such collaboration is attractive to firms are termed pre-competitive based upon the notion that each firm makes a judgment that the benefits from collaboration outweigh the opportunity costs from potential exclusion of competitors. The form of the collaboration, therefore, is important in understanding whether the participation of firms in joint research activities is really pre-competitive or if it is being used as a veil for collusive market activities covered under anti-trust statutes.

A litmus test for distinguishing pre-competitive research activities from collusive ones, therefore, would focus on the structure of joint research activities and how results are shared. For instance, "horizontal" research consortia which engage in activities broadly beneficial to member firms, such as SEMATECH and the Microelectronics and Computer Corporation (MCC), would appear to be pre-competitive. One would then ask whether the activities of such consortia led to unbalanced benefits to firms outside of the consortium, such as suppliers of advanced lithography equipment. If the answer is no, then the consortium is likely operating in a pre-competitive mode. On the other hand, if the answer is yes, then there would be a need to investigate whether such exclusive benefits were being conferred consciously or as a result of factors beyond the control of the consortium.

From a society-wide point of view, therefore, it is appropriate for government to be a catalyst to encourage collaborative, pre-competitive research activities among firms. Conversely, where collaborative behavior is not pre-competitive, such as vertical consortia aimed at the development of products or processes which are potentially rival and excludable, government should allow market forces to determine outcomes.

GEOGRAPHICALLY CONCENTRATED SPILLOVERS AND UNEXPLOITED GAINS

An especially significant characteristic of technology is that it is embodied not only in capital goods, but in people—so-called tacit knowledge. In turn, an important part of the uncontrolled spillover from a company's development of new technologies may be bottled up in a geographically specific region due to the concentration of human talents, long enough perhaps for firms in the region to benefit collectively from a temporary monopoly on the improved technological recipe.[21]

California's Silicon Valley and Boston's Route 128 are perhaps the best known contemporary instances of industry clustering in constrained geographic regions, but such clustering is by no means limited to what we think of as "high tech" sectors. There is a set of technologies, after all, that is specific to the carpet manufacturers clustered around Dalton, Georgia; the tile manufacturers clustered at Sassuolo, Italy; and the jewelry producers clustered around Providence, Rhode Island. All of these regional clusters are physical manifestations of the benefits that companies gain from accessing the spillovers from someone else's investment in technological innovation.

Regional clustering makes it easier for companies to access technological spillovers because information flows more easily locally than over greater distances. Even in this era of teleconferencing and electronic mail, the creation of specialized industrial environments, rich with relevant technical and scientific resources, facilitates the exchange of tacit know-how that is normally embedded in people but difficult for them to put into words. Furthermore, by concentrating a number of firms in a single industry in the same place, regional clustering creates a pooled market for workers with certain types of tacit knowledge and other specialized skills; this pooled market benefits both the workers, who can quickly and easily find many employers who need their know-how and skills, and firms, who can quickly and easily find a good choice of workers with the special skills and tacit know-how that the firms wish to acquire.

As noted before, some forms of technological information will spread rapidly, not only from firm to firm and from region to region, but from country to country. Whether through enhanced communications networks, international joint ventures, or more sinister

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[21] For more evidence and discussion of these points see, for example, Adam Jaffe, Manuel Trajtenberg, Rebecca Henderson, "Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations," *The Quarterly Journal of Economics,* Aug. 1993, pp. 577–598.

activities involving industrial espionage or patent infringement, new technology generated by a company in a national setting can increasingly generate spillover benefits for consumers and producers in the rest of the world. This is why much research and development can now be considered a national, or even an international, public good.

Other information related to a new technology remains so highly specialized, however, that it will stay internal to the firm that discovered it—like the way a new and particularly sensitive piece of production equipment works in a particular plant. Indeed, it is sometimes difficult for a company to transfer process knowledge between two of its own plants. In these cases, the firm can appropriate most of the economic returns from its investment.

Again, the interesting dilemma for policy makers involves the potentially large unexploited economic gains of collective action in an area lodged imprecisely between extremes—creating economic advantage out of tacit technological knowledge, the kind that spills over beyond the boundaries of individual firms yet tends to remain localized for considerable periods of time within regions. If regional actors can solve the free rider problem, then the daily process of feedback and exchange, of information sharing and the occasional pooling of resources among local firms, can nurture a unique regional technological capability. This can enable the region's firms to be more often first to market with innovative products, gaining for those firms both greater market share and greater opportunities for further learning, all of which adds up to a self-reinforcing cycle of development and growth.

Just as important, it creates within the region an enhanced ability to rapidly absorb and exploit footloose technological knowledge that has originally developed somewhere else. In other words, firms in the region are better able to exploit the kind of technological knowledge that diffuses rapidly from other places because they have already made the local investments necessary to quickly understand and apply it.

The presence of spillovers from the process of technological development creates limits to appropriability for inventors and free rider problems that can be solved only through collective action. But how large are the unexploited gains from collective action? How great are the potential benefits from special efforts by government to encourage the production of new technological recipes? The economic literature suggests that they are quite significant.

Recent surveys of the empirical evidence suggest that significant spillovers to research and development are present, and that, as a result of these spillovers, the social rate of return on investment in R&D far exceeds the private rate of return, despite the availability of patent protection.[22] Recall that the private rate of return is the yield on the original investment in the technology captured by the innovator; the social rate of return is the aggregate rate of return to the economy, including the spillovers or additional returns captured by consumers and producers who use or imitate the original innovation.

Private benefits are typically estimated in terms of profits realized by the innovating firm; to capture the aggregate economic or "social" benefits due to spillovers from the innovation, savings to the buyers as well as profits to imitators of the original innovation are estimated. Costs are calculated for the R&D required to produce the new product or process as well as for manufacturing and marketing the innovation. This kind of calculation has also been done at the national level using econometric techniques with total factor productivity as the benefits variable and total expenditures on R&D by the firm or industry as the technology investment variable. The best guess of economists, based on all the available evidence, is that the social rate of return to R&D investments in technology is very large, on the order of 30 to 50 percent.[23]

The evidence that social rates of return to R&D far exceed private returns—by 35 to 60 percent above the return to ordinary capital, according to one conservative estimate[24]—suggests that substantial spillovers are indeed present. In other words, firms that invest in the development of new technological recipes have only weak control or property rights over those recipes once they exist. This is good for making sure that new technology diffuses rapidly and widely, but it means that the incentive to discover new technologies in the first place is much weaker than it needs to be from the perspective of potential aggregate returns to the economy. Thus there is a strong intellectual justification for collective action through government to encourage research and development.

Even though the spillovers generated by research and development can be shown to be large, it remains true that the incentive for any one country's government to support

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22 M. Ishaq Nadiri, "Innovations and Technological Spillovers," Working Paper 4423, National Bureau of Economic Research, August 1993

23 Ibid.

24 Martin Neil Baily and Alok K. Chakrabarti, *Innovation and the Productivity Crisis*, Brookings, 1988.

R&D may still be limited, precisely because of the uncontrollable nature of the spillovers. Simply put, many of the benefits of novel technological approaches discovered in one country may in fact accrue to the benefit of firms and consumers in other countries. The problem of limited appropriability at the level of the nation, not just the firm, is probably less troublesome for an economy the size of the United States, but it is nevertheless important. One response to this dilemma might be for governments to pursue the development of international mechanisms to subsidize research and development.

Another possible response, especially for domestic politicians concerned that their constituents capture the lion's share of the economic returns to investments made with their tax dollars, would be for governments to target some of their R&D investments on enhancing the technological infrastructure of regional agglomerations within their national boundaries. Whereas the existence of spillovers means that dispersed funding of research and development is often as likely to benefit foreign producers and consumers as domestic ones, the geographically specific or "local" nature of some of the spillovers provides an opportunity for governments to use localized investments to create spillovers that are geographically confined. Because the spillovers will remain localized or geographically confined for some period of time—perhaps a very long time—the spillovers will disproportionately benefit the local economy.[25]

Note, however, that this logic does not by itself provide policy makers with any direction as to which particular clusters of industry or technology they should support or how big a subsidy they should provide. It tells them, rather, in very general terms, that government subsidies for region-specific R&D centers can be justified. Indeed, the econometric estimates economists have made of social rates of return to R&D after the fact suggest that econometric estimates alone are incapable of providing precise guidance about where to direct research dollars before the fact.

NATIONAL TECHNOLOGY POLICY IN A GLOBAL ECONOMY: HOW EFFECTIVE?

Based upon the foregoing, we argue that even in this era of teleconferencing and fax machines, spatial agglomeration or clustering within geographic regions retains its unique capacity for bottling up, or localizing, certain types of technological information. Indeed, the fact that spatial decentralization of enterprises has been made cheaper and

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[25] Bennett Harrison, "The Geography of Innovation," *Technology Review*, January 1995, p. 62.

cheaper due to advances in both communications and transportation has actually made regional specialization easier. The difference, now, is that regional clusters may be becoming more specific to particular parts of the production process within an industry or linked set of industries—basic research, advanced manufacturing and prototype development, volume assembly, specialized sales—instead of being specific to the entire industry. Thus the rise of science parks, design centers, and export processing zones.

This is part of the explanation for the observed increase in foreign direct investment in recent years. Foreign direct investment is used increasingly by globally distributed enterprises to access the kind of tacit, difficult-to-articulate know-how that circulates within specialized regions but is slow to diffuse outside of them. This is why companies often locate research and development facilities abroad before committing to putting manufacturing and after-sales service facilities abroad as well.

All of this has implications for national technology policy. Indeed, given the main economic justification for government action—the existence of large unexploited social returns due to the limited ability of individuals or firms to appropriate the economic returns from their discoveries—the fact that new communications technologies accelerate the diffusion of technological information across national borders means that nations—not just individuals or firms—may have increased difficulty appropriating the economic returns from research and development conducted within national economies. What used to be national public goods are now international public goods; what used to be national industry-specific public goods are now international industry-specific public goods. What are the objectives of national technology policy in such an international environment?

The overall objective should be to prevent or neutralize the progressive balkanization of global markets for emerging technology. Without such efforts, strategic trade policies may limit the size of potential markets. This could reduce the economic returns from R&D investments and thus lead to less investment in technological discovery worldwide. The rate of technological innovation and economic growth would slow, and average standards of living would stagnate or decline, across the globe.

By focusing on three objectives, domestic technology policies can drive towards this main goal. The first is to assure access for domestic producers to emerging technology. The second is to ensure that entire sets of national producers are not locked in to an inferior technology trajectory when radical innovations emerge abroad. The third

is to promote the rapid and widespread diffusion of know-how in the domestic economy to permit the effective application of new technologies invented both at home and abroad.

The first objective raises the complex issue of access transcending national borders—specifically, who should have access to government-supported R&D projects in the United States? This presents U.S. policy makers with a difficult strategic decision: Should access for foreign firms to U.S. R&D funds be used to ensure that U.S. companies gain access to government-supported R&D projects in other countries?

The ideal principle would be national treatment for every country's investments in other countries. For example, a foreign firm investing in the U.S. would be treated exactly like a U.S. firm investing in the U.S. Not insignificantly, the principle of national treatment would effectively do away with the need to make legal distinctions between foreign-owned and U.S.-owned firms, distinctions that are increasingly difficult to make in this era of globally distributed enterprise and international multi-firm alliances.

However, until the necessary international agreements for implementing the principle of national treatment are put into place, the interim principle should be reciprocity. Foreign firms should enjoy the same degree of access to research and development efforts in the United States as U.S. firms are granted to research and development efforts in corresponding nations. A reciprocal principle permits governments to support socially beneficial R&D while helping to neutralize the strategic efforts some governments might otherwise undertake to create monopoly advantages for their own domestic producers.

The principle of reciprocity in access to R&D reinforces the international public goods aspect of technology development. It does not, however, remove the temptation to governments and producers to "free ride" on the technology investments of governments and producers in other countries. It will be necessary, then, for governments to negotiate a fair and workable allocation of the burden of financing the least appropriable forms of research and development. This means, in turn, that mechanical performance rules for conditioning participation in government-funded R&D projects do not make sense; flexibility, a capacity to make trade-offs, is key.

Performance rules that govern access are increasingly common and certainly understandable from a political point of view. American taxpayers deserve assurances from their elected officials that they and not just the taxpayers of other countries are receiving tangible economic returns from investments the officials are making with their

money. Nevertheless, rigid performance rules can quickly degenerate into protectionist devices that actually slow the rate of technological innovation and growth for everyone.

Rules like "all research and development supported in whole or part by the United States government should be performed in the United States" may enhance the capacity of U.S. regions to capture local technology spillovers, but they could also lead to retaliatory measures by foreign governments which might keep U.S. companies from gaining early access to technology spillovers generated in technology projects overseas. Rules like "all products arising from research and development supported in whole or in part by the United States government should be manufactured entirely in the United States" can interfere similarly with access to foreign markets, as well as making U.S. firms noncompetitive on costs in industries where manufacturing is only a small share of value added.

The strictest rule of all—"foreign participation is prohibited in research and development projects funded in whole or in part by the United States government"—would almost certainly lock out foreign firms that could otherwise bring critical technological assets to the project. In this case, the U.S. would be shooting itself in the foot because collaborative ventures and technology links with foreign firms can reduce innovation costs and enhance the technological competence of collaborating U.S. firms to the overall benefit of the U.S. economy. The worst possible policy would be to deny the U.S. economy foreign know-how that would otherwise benefit U.S. economic growth and U.S. productivity. So long as foreign producers transplant the full range of their most advanced activities into the United States, and so long as their domestic markets are open and competitive, foreign ownership ought not to matter.

No one set of criteria is useful by itself for assessing whether participation by a particular firm is in the U.S. economy's long-term interest. Instead, the United States needs to devise a flexible, discretionary approach that broadly assesses the current and long-term impacts of that firm's technology development activities on the domestic economy. A reasonable approach would be for U.S. policy makers to develop a flexible national benefits framework that could then be used to "score" any firm that applied for U.S. government funding to engage in research and development. Reciprocity could be one of the benefit measures applied to firms that are predominantly foreign-owned, but evidence of reciprocal treatment of U.S. firms by the home government might be deemed less important to the foreign firm's overall score if that firm committed to bringing important proprietary technological know-how to the project.

Under this framework, for instance, a responsible Cabinet official might be given the discretion to accept, reject, or make conditional a firm's participation in federally funded R&D, whether the firm is foreign or U.S.-owned, based on a broad evaluation of the potential participant's contributions to the domestic economy. Potential contributions would be measured according to a set of indicators. These might include, for example:

(1) data on the geographic distribution of assets, employment and facilities for conducting research and development

(2) data on ownership and control, including corporate nationality for purposes of taxation and profit repatriation

(3) data on the geographic sourcing of parts/services

(4) an analysis of industry structure

(5) foreign reciprocity in trade, investment, intellectual property protection, and other forms of technology access

(6) national security/social value considerations

In looking at these data, U.S. officials should be interested not just in current numbers but in trends—is the firm trending toward a greater or lesser contribution to the U.S. economy? The initial burden of proof should be on the potential participant to demonstrate both its current economic contributions and its anticipated future ones, as part of a submission for participation in U.S. funding.

Clearly, the principle of reciprocity, let alone national treatment, is not yet subject to effective international enforcement. Thus the second objective of domestic technology policy should be, in effect, to spread the country's technology bets. That is, government should work with private industry to broaden the domestic search for new technological recipes in areas that seem to promise high social returns. This will lessen the risk that entire sets of national producers could get blind-sided—and perhaps locked in to an inferior technology trajectory—by radical technological departures discovered by competitors abroad.

Finally, the third objective of technology policy should be to promote the rapid and widespread diffusion of know-how that permits effective technology application. Many commentators have noted in recent years that U.S. firms seem to have difficulty applying and commercializing home-grown innovations. Increased attention to the problem of diffusion and application is necessary to improve the capacity of domestic producers to commercialize the innovations they make, and to apply the innovations discovered by others both at home and abroad.

This enumeration of domestic objectives for technology policy leaves unanswered, for the moment, the critical question of means. How should policy set priorities and decide where to place limited public investments? How can policy subsidize technology development in certain areas without dampening market signals? When should policy seek to help national producers or regions to extract monopoly rents from technology innovation, and when should policy emphasize the diffusion of technology and the development of sophisticated markets to induce further research and learning-by-doing? Are there circumstances in which policy should seek to shape the trajectory of technological development, or should government technology investments faithfully follow the instincts of investors in the private sector? And how do policy makers decide when to withdraw public support from programs that are clearly not working?

CONCLUSIONS

It is our position that, considering the empirical results at both the macroeconomic and microeconomic levels, where there is strong evidence that market failures exist and inhibit or deter private sector technology investments, government is justified in pursuing improvements in social welfare and should use the most effective policy tools at its disposal, whether micro- or macroeconomic in nature.

What do we now know about successfully conducting public sector technology investment programs to stimulate economic performance and growth? While it is still too early to judge the Clinton administration's efforts on the basis of outcomes, a much clearer understanding of what may be accomplished by government, and what should be avoided, is emerging.

The experience with public sector technology investments for economic growth and competitiveness suggest that in the future some modification should be made to the approaches employed in choosing technology areas and the selection of particular investments. We offer the following four principles for use in guiding the choice of future technology investments by the public sector.

First, to maximize the social benefits from public sector technology investments government should take better account of market impacts and opportunities in deciding when and where to commit funds, *but agency missions—that is, clearly stated national objectives—should maintain first priority.* Economic competitiveness or the

maximization and exploitation of spillover benefits from technology development, while essential, should be derivative or subsidiary to agency mission objectives.

Second, there is a need to better operationalize the concept of pre-competitive investments to make it possible for government to stimulate collaborative research activities among firms without running afoul of differing political ideologies. This would assist in realizing the potential broad social benefits that accrue through the development of non-rival and non-excludable goods.

Third, government should pursue programs that assist in the development of geographic concentrations of tacit knowledge as a means of domestically anchoring U.S. technological advantages. The natural candidate for such programs are U.S. universities and colleges situated in areas which contain significant concentrations of complementary industrial and technological activities.

Finally, the U.S. should aggressively pursue national treatment policies for government technology programs and other government supported activities to assure U.S. firms' continued access to foreign technologies. Only with such an approach to the global technology base will U.S. firms be able to prosper in the face of rapidly growing foreign competition into the 21st century.

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This paper explores the recent Clinton administration technology policy and makes observations and recommendations regarding areas of apparent success and failure. The authors apply their collective knowledge of the administration's ongoing efforts to draw conclusions about the appropriate role of government in stimulating economic benefits through technology "investments."

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